

Measuring Atomic-Scale Optical Imperfections for Future Microchip Generations

For 30 years, the density of circuit elements on microchips has doubled roughly every two years, resulting in progressively smaller, faster, and cheaper computers. To continue this rate of progress into the next century, we will require extremely precise and accurate optical components that can focus light sharply enough to “etch” up to a billion circuit elements onto a square centimeter of silicon. Crafting such precision optical components requires equally precise and accurate measurement tools, such as the phase-shifting, point-diffraction interferometer (PS/PDI) that has been developed at the Advanced Light Source (ALS).

The size of the circuit features that can be mass-produced on a microchip depends on the wavelength of light used to etch the features onto the chips. Past reductions in feature size were primarily achieved by using shorter wavelengths of light. However, industry experts predict that, in a few

years, we will reach a wavelength at which the refractive lenses used for focusing will absorb light rather than transmit it. Anticipating this roadblock, the semiconductor industry has developed a “roadmap” that explores several options for getting around this limit within the next decade.

One of the options uses the reflection (as opposed to refraction) of light at 13 nm, an extreme ultraviolet (EUV) wavelength optimized for use with curved mirrors coated with multilayers consisting of a large number of alternating scattering and transmitting layers with thicknesses less than the distance over which the radiation is absorbed. The mirrors are curved to form a reduced image of the circuit patterns onto the microchip, and the thicknesses of the layers are chosen so that the light waves reflecting from each layer add constructively. Since this is a resonant system tuned to 13 nm that is extremely sensitive to changes in wavelength, angle of incidence, and

layer thickness, aberrations caused by coating defects and thickness errors can only be measured using 13-nm light. Furthermore, the required fabrication tolerances are incredibly stringent: to verify the shape of such a mirror, we need a measurement tool with an accuracy of 0.10 nm—smaller than the size of a single atom!

The PS/PDI is a measurement tool designed to meet these specifications. This interferometer is permanently installed on Beamline 12.0 at the ALS, which is the best available source of very bright, highly focused 13-nm light. The beam first passes through a pinhole, which uses spatially coherent undulator radiation to produce a spherical wavefront. A diffraction grating splits the light into several beams that reflect off of the mirrors being tested. One beam (the test beam) passes through a window large enough to preserve the aberrations picked up from the test mirrors. Another beam (the reference beam) passes through a second pinhole

that is small enough to “filter out” the aberrations, again producing a uniform, spherical wave. When the two beams interfere, they produce a pattern of light and dark fringes that yields information about flaws in the test mirrors.

To determine the interferometer’s accuracy, the researchers replaced the test-beam window with another pinhole, in effect producing two reference beams. The interference between the two reference beams reveals the systematic error introduced by the interferometer itself. This was found to be just under 0.05 nm, a significant improvement over the design goal of 0.10 nm, and well beyond the current state of the art in optical metrology. Although a commercially viable chip manufacturing process would still be six to ten years away, this achievement represents an important milestone that paves the way for the potential use of EUV light in producing future generations of microchips.

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P. Naulleau, K.A. Goldberg, S. Lee, C. Chang, C. Bresloff, P. Batson, D. Attwood, and J. Bokor, “Characterization of the accuracy of EUV phase-shifting point diffraction interferometry,” *SPIE* 3331(1998) 114.



EXTREME ULTRAVIOLET (EUV) INTERFEROMETRY



Measuring Atomic-Scale Optical Imperfections for Future Microchip Generations

- **Semiconductor industry “roadmap” for microchips**

- *Density of circuit elements doubles every two years*
- *Smaller circuit features → shorter wavelength light*
- *Wavelengths approaching limits of refractive optics*
- *Developing new technologies to keep up pace*

- **Extreme ultraviolet (EUV) lithography**

- *One of several options being explored by industry*
- *Big wavelength jump from DUV (248 nm) down to 13 nm*
- *Curved, multilayer-coated mirrors for pattern reduction*
- *Extremely stringent tolerance requirements on mirrors*

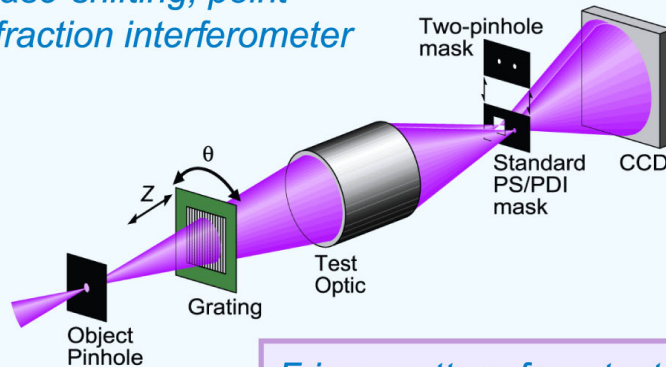
- **Phase-shifting, point-diffraction interferometer (PS/PDI)**

- *Measures tiny imperfections in EUV mirrors*
- *Uses coherent 13-nm undulator radiation available at ALS*
- *Demonstrated accuracy of 0.05 nm, less than size of 1 atom!*

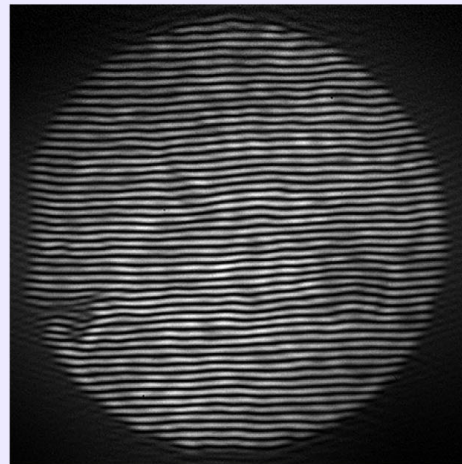
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Phase-shifting, point-diffraction interferometer



Fringe pattern from test mirror yields figure errors



Fringe pattern from "null" test demonstrates interferometer accuracy

